QUALITY AND RELIABILITY OF BGA AND SMT COMPONENTS

by

Reza Ghaffarian, Ph.D.
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

ABSTRACT

Spacecraft electronics including those used at the Jet Propulsion Laboratory (JPL), demand production of highly reliable assemblies. JPL has recently completed an extensive study, funded by NASA's code Q, of the interplay between manufacturing defects and reliability of ball grid array (BGA) and surface mount electronic components.

More than 400 hundred test vehicles were assembled using ceramic and plastic BGAs, LCCs, J-leads, and gull wing components. These were subjected to thermal cycle testing and solder joint defects were logged prior to testing, and solder damage propagation over time was documented. These findings offer valuable information to designers and quality assurance personnel alike on package robustness as well as in better understanding the defects that can actually lead to failure. Results of findings will be presented.

INTRODUCTION

OBJECTIVES

NASA Headquarters, code Q, has established an Electronic Packaging and Assembly Program to address the common needs of NASA programs. One of these programs funded during 1993-1995 focused on the use of SMT for high reliability, Ultra Low Volume (ULV) spacecraft electronics as used in the NASA community. The other funded during 1994-1996 concentrated on evaluation of quality and reliability of Ball Grid Arrays.

Aspects of SMT technology were carried out by four RTOPs (Research & Technology Objectives & Plans) at NASA's Jet Propulsion Laboratory. These RTOPs are interdependent and were conducted concurrently. Each RTOP concentrated its efforts on a particular aspect of the design, modeling, manufacturing, test, and deployment (aging) cycle. The primary objectives of the RTOPs were as fo] lows:

- Identify the critical parameters of SMT manufacture. Determine the methods and tools required to integrate QA procedures into the design and manufacturing processes so that the critical parameters can be bounded and controlled.

- Develop a thorough understanding of the creep-fatigue mechanisms underlying solder joint failures of surface mount electronic packaging systems. Develop generic, broadly applicable design guidelines, analysis methodologies, and data requirements.

- Develop an assembly level qualification test methodology for surface mount technology and apply this methodology to electronic packaging systems through the use of experimental design techniques and phased experimentation.

- Disseminate NASA Guidelines for SMT, developed from the knowledge gained from the JPL RTOPs, as well as the efforts of other NASA centers, industry knowledge centers, and industry partners.

References 1-9 document some of activities performed in the SMT RTOP areas. in conjunctio n with the RTOPs, a survey and a series of Phase 1 and Phase 2 cooperative test programs involving all RTOPs were performed. A summary of the results are presented.

The objectives Of the Ball Grid Array project were to demonstrate the robustness, quality, and reliability of BGA technology, and to assist in the development of the rapidly growing industrial infrastruct ure for this technology. BGAs are electronic packages used for higher 1/0 (Input/Output) counts that also provide improved electrical and thermal performance and more effective manufacturing and case of handling compared to the conventional Surface Mount (SMT) leaded parts.

To meet requirements of NASA community, including JPL's, for highly reliable assemblies in an Ultra-Low Volume (ULV) environment, an integrated system approach was used. The foci included identification of BGAs' critical manufacturing parameters, evaluation and development of inspection techniques, and determination of the effects of manufacturing defects on solder joint reliability. The Quality Assurance (QA) procedures developed will then be integrated into design and manufacturing so that critical parameters can be bounded and controlled.

JPL solicited industrial, academic and other related consortia to work together to leverage their resources and expertise into a synergistic effort. All participants furnished in-kind contributions. The wide industrial use of BGA technology will afford NASA as well as consortium industries inexpensive access to this technology and support miniaturization thrusts for their next generation applications.

The consortium objectives were to complete characterization of BGAs in the following areas:

- Processing/assembling Printed Wiring Boards (PWBs) using BGAs. Variables included PWB's material types and surface finishes, and use of ceramic and plastic packages with different balls populations and 1/0s,

- Identifying inspection and Quality Assurance (QA) methods for ascertaining the process controls, acceptance methodologies, and establishing final quality of BGA assemblies. Characterizing package properties such as coplanarity, inspection for solder joint quality, damage progress recording during environmental exposure, and defect/reliability correlation as well as estimating life of solder joints.

- Investigating the reliability of BGA assemblies in several (iii'lcnmt environments (thermal and dynamic).

A large number of variables inside the design, manufacturing and test of the Lest vehicles (TVs) were statistically toggled using a Design of Experiment (DoE) technique to determine the influence and criticality of these variables. References 1 ()-12 document some of the activities on the BGA Program.

SMT- CONVENTIONAL COMPONENTS

SMT SURVEY

NASA centers involved with SMT were surveyed in 1993 (Reference 1). One section of the survey addresses QA issues for SMT hardware. The objectives of the SMT QA survey were to identify the critical parameters of the SMT manufacture and to determine the methods and tools presently used by industry to identify and control them. It was concluded that the leading causes of SMT rejects were solderability and solder paste (imposition problems. Some operations did not have corrective action feedback loops to change a design or process even when data indicated a problem.

PI IASE 1 TEST PROGRAM

The Phase 1 test involved the use of a single ceramic component, ().()5() inch pitch, soldered to an epoxy-fiberglass FR-4 board (Reference 4), LCCs, J-lead cerquads, and gull wing cerquads were the SMT components. The JPL SMT Training Facility assembled 20 and the Electronics Manufacturing Productivity Facility (EMPF) in Indianapolis, Indiana assembled 205 test boards.

Thermomechan ical cycle testing (-55°C to 100°C, 45 minutes dwells and duration of 246 minutes) on Phase 1 assemblies having LCCs, began in August, 1993. All LCC assemblies have failed (open circuit). Two-parameter Weibull equations were used to characterize failure distribution (Figure 1). Phase 1 testing of the J-leads was initiated in January, 1994, and now (December 1996) has reached more than 3,500" cycles with no failure. Testing of the gull wing cerquads started in July, 1994, and they have now accumulated more than 3,500 cycles with numerous failure with the first failure at 1,720 cycle.s (Figure 2).

1'1 IASE 2 TEST PROGRAM

Phase 2 used several different types of packages similar to phase 1 as welt as capacitors and resistors on a polyimide board. The overall purpose of the Phase 2 testing was to perform statistically significant testing of surface mount assemblies to better understand the fail ure modes and inherent fatigue life of the solder interconnect, and to continue development of tailored qualification methods. Critical SMT manufacture parameters were controlled to determine their effects and to further develop QA methodologies. Design of Experiment (DOE) test methodology was utilized to meet these objectives. The DOE was a hybrid of full factori al anti partial factorial approaches. The majority of environmental testing will consist of flijj$i-like thermal cycling, i.e., thermal cycling within a vacuum environment.

Solderability of gull wing, lead remnants were evaluated for comparison to gull wing manufacturing defect. The dip-and-look qualitative test method was used at the vendor site and a quantitative Multicore Universal Solderability Tester (MUST) that measures wetting force was used at J]>].. The vendor tested about twenty and JPL tested approximately 500 strips of leads. Leads were held in place by a plastic strip in bundles of 41 and 64 leads representing a side of 164 and 256 gull wing packages, respectively. Results of visual inspection, dip-and-look, and MUST print-out data were compared for 164 and 256 gull win packages. Based on the dip-and-look test results, all of the 164 and most of the 256 gull wing leads failed solderability testing. Results of solder joint assembly inspection contradict the dip-and-look test results for the 164 gull wing leads whereas they agree, with results of the of 256 leads.

SMT TEST RESULTS

PHASE 1- CYCLES TO FAILURE AND WEIBULL DISTRIBUTION

Figure 1 shows cycles to failure for 68-, 28-, and 20-pin LCC assemblies. Failures were detected by Anatech® and verified by visual inspection. The failure distribution percentiles were approximated using a median plotting position, $F_i = (i-0.3)/((n+0.4)$. As expected, there was a large spread in cycles to failure because of variance in solder joint volume, quality and location. The first failure for the 68-pin LCCs was detected at 53 cycles while the last sample failed after 139 with 93 average cycles. 28-pin LCCS failed at much higher cycles in the range of 352 to 908 with 660 average cycles. The 20-pin cycles to failure were in the same range as for those of 28-pins and failed within 573 to 863 averaging 674 cycles.

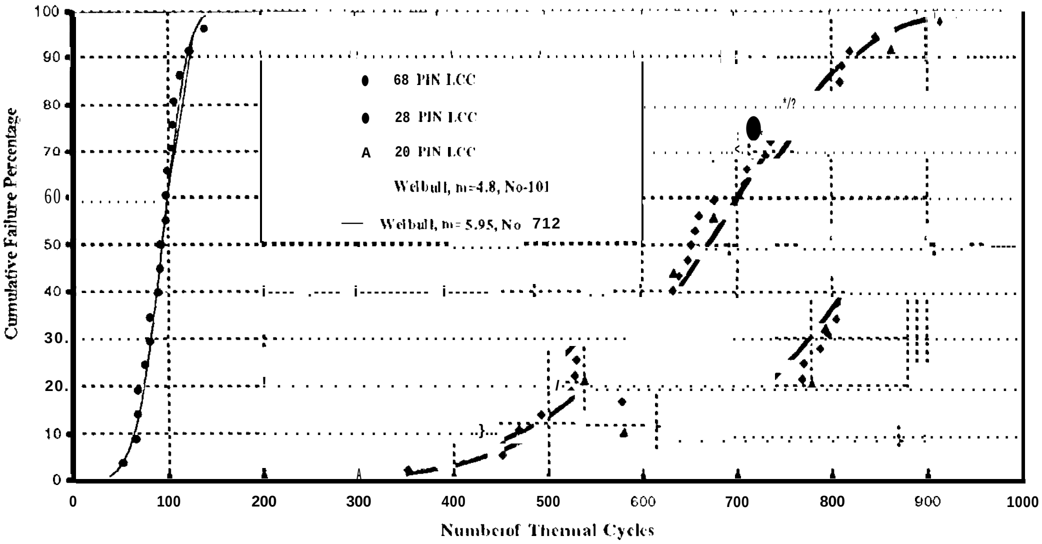


Figure 1. Cumulative Failure Distribution Plots for LCC Assemblies

If only Distance from Neutral Points (DNPs) are considered, the 20-pin LCCS should have failed at higher cycles. Cycles to failure is directly proportional to DNP. However, cycles to failure also inversely depends on the effective solder fillet height. Solder fillet height for 20- and 28-pin LCCs was .021 and .033 inches respectively, which is lower for a 20-pin resulting in higher shear strain for the same CTE mismatch displacement. The difference in part size could have been off-set by the difference in the fillet height.

Often, two-parameter Weibull distributions have been used to characterize failure distribution and provide modeling for prediction in the areas of interest. The Weibull cumulative failure distribution was used to fit 68- and 2.8- pin LCCs' cycles to failure data. The Weibull graphs are plotted in Figure 1 as solid and dash lines for 68- and 28-pins, respectively. For 68-pin LCCs, the scale and shape parameters were 101 cycles and 4.8, respectively. These were 712 cycles and 5.95 for the 28-pin LCCs. Both data sets showed excellent linear correlation in log-log plots with a coefficient of correlation of at least 0,97.

Majority of 68-pin gull wing assemblies with kovar leads have failed between 1,720 cycles and 3,500 cycles, None of gull wings with alloy 42 lead and J-lead assemblies have failed to 3,500 cycles. Figure 2 compares cycles to failure for LCCs and those of 68-pin gull wing assemblies. Results shown are for 10 gull wings out of total of 13 assemblies with kovar leads. The first failure occurred at 1,720 cycles and the 11th failure was between 3187 and 3217 cycles.

Similarly to LCC assemblies, two-parameter Weibull distribution was fitted to cycles-to-failure data. For 68-pin gull wing, the scale and shape parameters were 2,888 cycles and 5.7, respectively.

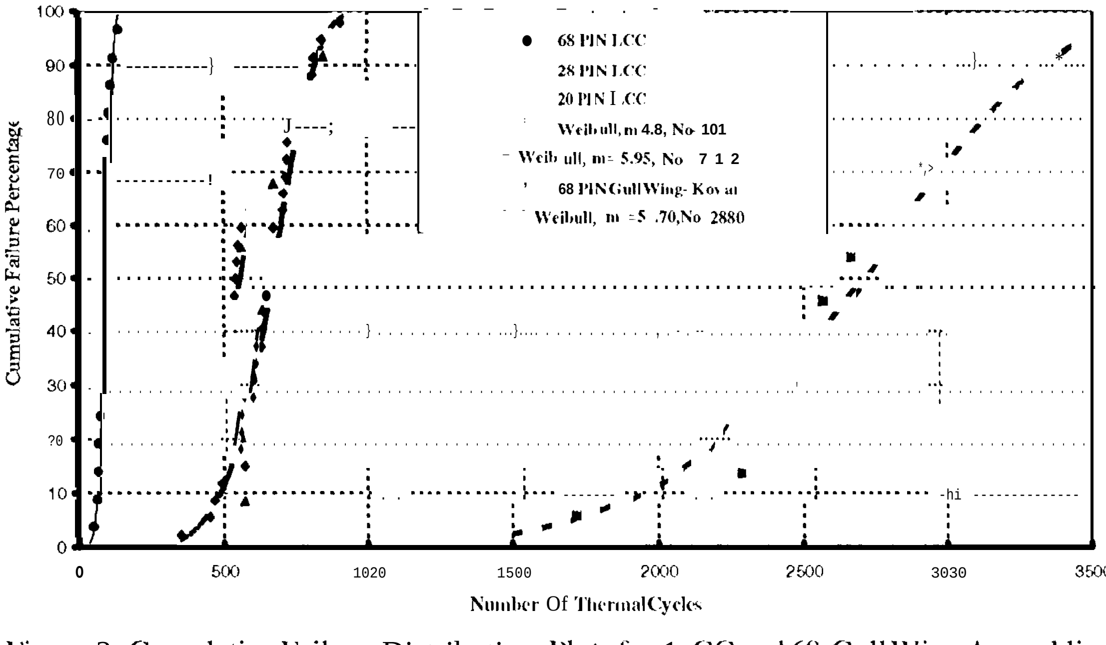


Figure 2. Cumulative Failure Distribution Plots for LCC and 68-Gull Wing Assemblies

INSPECTION CORRELATION TO S01 .DERABILITY RESULTS

'1'able 1 lists dip-ad-look, MUST print out test data and solder joint inspection results. Values for dip-and-look arc approximate area percentages of non-coverage solder areas. F, r, and S parameters are those read from MUST print-outs. These parameters are automatically calculated based on the wetting section 01 the crew, i.e., time to begin welling to time to maximum wetting force.

The plot portion approximate to an exponential, that is the force f at any time t is considered to be a function of the maximum force F_{max} and the time constant **S.**

$$f = F_{max} (1 - \exp(-t/S))$$

The "wetting speed" changes with lime and is a function of the time constant S. The force **f** changes from the maximum negative wetting force to the maximum positive force. S is measured in seconds, when **t=S,**
f = 0.632 F_{max}. F_{max} and **S** can be calculated from the force/time curve. The MUST wetting balance takes force readings every 0.1 seconds, and the best fit of data to a straight line of log-log of this equation, The value F_{max} and S are calculated from the regression line together With the coefficient of correlation r, which express how closel y the observations fit a straight line.

Based on the dip-and-look test results, all of the 164 and most of the 256 gull wing leads failed solderability testing (non-coverage area more than 5%). Results of solder joint assembly inspection contradict the dip-and-link test results for the 164 gull wing leads whereas they agree with results of the of 256 leads. It should be noted that the 164 leads had a tin coating layer whereas the 256 leads had a gold coating layer. It is possible that the test results were influenced by surface coating conditions. This needs to be further explored.

The print out values of **r**, S, and **F** give some indication of solderability. The **r** (dimensionless) indicates uniformity of wetting and should exceed 0.8 when wetting is uni form everywhere. S, in seconds gave some indication of the speed of wetting. A value of less than 1 second shows rapid wetting which is considered to be good. The tots] wetting force, **F**, depends on the perimeter of the specimen and when divided by the perimeter value in mm gives the wetting strength.

TABLE II Lead Solderability Test Results And Solder Joint Inspection

Serial Number	Time Constant (sec)	Correlation Coefficient	Wetting Balance Force (grams)	"Dip & Look" non-coverage	Dip & Look Pass/Fail	Visual Inspection
164 GW	S	r	F	(%)		
6	0.407	0.951	0.734	25	Fail	OK
9	0.258	0.966	1.060	10	Fail	OK
32	0.269	0.970	0.579	10	Fail	dewet,nonwet
36	0.569	0.876	0.367	20	Fail	OK
62	0.334	0.964	0.541	25	Fail	No inspection
68	0.543	0.855	0.509	35	Fail	OK
69	0.797	0.741	0.906	30	Fail	dewet
79	0.881	0.933	0.538	15	Fail	dewet
256 GW						
1024	0.357	0.971	1.320	5	Pass	OK
1034	0.346	0.962	1.126	1	Pass	OK
1035	0.413	0.916	1.426	20	Fail	bridge
1037	0.410	0.866	1.518	30	Fail	open
1044	1.205	0.426	1.971	5	Pass	OK
1045	0.738	0.687	1.378	5	Pass	OK
1046	0.352	0.980	1.091	1	Pass	OK
1049	0.612	0.699	1.695	?	not cleaned	OK
1061	0.193	0.971	1.075	5	Pass	bridge

CERAMIC AND PLASTIC BALL GRID ARRAYS

INTRODUCTION

The production of surface mount assemblies (SMAs) now surpasses assemblies using through hole technology ("THT"). In SMT, components are mounted and terminated directly onto PWB surface. One of the most important component parameters is the lead pitch, which is continuously decreasing to meet the need for higher I/O count.

The use of fine and ultra fine pitch (FP and UFP) components with less than 0.020 inch pitch is growing, often resulting in more than 200 leads for a single device. Typically, these components have gull wing leads. FP and UFP components, in addition to being extremely delicate and easily damaged during handling, are also difficult to process and rework, and are prone to misalignment with the associated reliability implications.

BGA is an important emerging technology for utilizing higher pin counts, without the attendant handling and processing problems of the peripheral array packages (PAP). Unlike PAPs, BGAs have balls, covering the entire area, or a large portion of the area on the bottom of the package.

BGAs offer several distinct advantages over FP and UFP SMCs that have gull wing leads, including:

- 1 ligh pin counts, generally > 200.
- 1 .arger lead pitches, which significantly reduces the manufacturing complexities for high I/O parts.
- Higher packaging, densities, since the lead envelope for the gull wing leads (1ocs not apply to BGAs; hence, it is possible to mount more packages per board.
- Faster circuitry speed than gull wing SMCs bc.came the terminations are much shorter.
- Better heat dissipation than gull wing leaded SMCs because of providing lower path from die to PWB for heat dissipation.
-

BGAs are also robust in processing. This stems from their higher pitch (0.050 inch typical), better lead rigidity, and self-alignment characteristics during reflow processing.

BGAs, however, arc not compatible with multiple solder processing methods and individual solder joints cannot be inspected and rc.worked using conventional methods. in ultra low volume SMT assembly applications, e.g. NASA's, the ability to inspect the solder joints visually has been standard and is a kcy factor for providing confidence in solder joint reliability.

CONSORTIUM TEAM MEMBERS

At the start of the project, in January of 1995, a core of consortium team members was formed. Its members included Hughes, Boeing, and 1<1'1'. In weekly teleconferences, the consortium defined their needs, shared their experience and strengths, and knowledge gained on BGA technology through their independent literature searches. Consortium members visited companies with experience in BGAs to better understand the state of the technology and the areas that the consortium could address to add value to the advancement of technology.

JPL organized a workshop on 3 March 95 to have, fxc-to-face information exchange among the core consortium team members and new participants. Participation by Interconnection Technology Research Institute (1'1'1{1) and S1}MA'1'JK11, a visionary organization in electronics technol ogy, perm itted further narrowing, of the project focus activities. ITRI, a focal point for the collaboration among the industries, was key in facilitating future expansion of the consortium into the commercial sectors, The consortium shared invaluable information, and built further confidence in BGA technology. Variables for the test matrix definition were. ranked based on the current and future needs of the consortium.

The test matrix went through many revisions as new members joined and was finalized by September '95 when Altron agreed to fabricate both FR-4 and polyimide PWBs and Celestica agreed to assemble most of the test vehicles. The organizations that have been an integral part of the consortium activities are as follows:

- **Military scdors-** Hughes Missile Systems Company (HMSC) designed the PWBs, Boeing Defense and Space Group performed environmental testing for military applications. I oral (Lockheed- Marlin), Canada, offered to assemble and test validated the reliability of an additional 200 test vehicles using the consortium test matrix and test vehicle design.

- Commercial **facilities-** Amkor/Anam Electronics, inc. provided more than 700 plastic packages, Altron inc. fabricated 300 PWBs using FR-4 and polyimide materials, Celestica, Canada, assembled 200 test vehicles, Electronics Manufacturing Productivity Facilit y (EMPF) pert'ormc(i environmental testing, American Micro Devices (AMD) provided resistive die, IBM provided ceramic packages at a minimum charge, Nicolet assisted in X-ray, and View Engineering measured coplanarity and warpage of packages using their 3-D laser scanning equipment.

- **infrastructure-** 1'1"1<1 established by the Institute for Interconnecting and Packaging Electronic Circuits (IPC) has provided a vehicle for collaboration among the various sectors of electronic interconnection industries.

- **Academia-** Rochester Institute of Technology (1{1'1') assembled 35 test vehicles. More than 20 industrial advisors including people from JPL are helping to redirect the RIT recta] manufacturing laboratory into a Computer Integrated Electronics Manufacturing (CIEM) facility to better meet the current national demand for electronics manufacturing engineers.

TECHNICAL ISSUES

1'1'1<1's presented viewgraphs at the J]']. Workshop depicting the relationship between pin count and cost/performance. It was apparent that peripheral leads will soon fall short of meeting advanced packaging requirements. Cost/performance requirements for QFPs to meet near term future requirements were even more disparate. However, for BGAs there was a wide range of I/O, pitch, and sizes meeting both a near term demand and expected future long term requirements.

in reviewing packaging technology trends, S1 EMATECH forecast different types of electronic packages for surface mount applications. These included plastic quad flat pack (QFP), plastic ball grid array (PBGA), ceramic ball grid array (CBGA), and thin tape carrier packages ('1'(T). Comparison of low, medium and high 1/0 counts were presented. ']'here were QFP packages in the medium range while at high 1/() count only BGAs and TCPs were cost/performance competitive.

Many other technical issues were discussed related to the selection of test matrix parameters for the investigation. Issues discussed included:

- Further definition of test vehicles based on the objectives and needs of industry.
- Pretesting before evaluation for test vehicle optimization.
- Need to leverage the work performed by others. Enough data were available that many manufacturing variables did not have to be considered.
- S1 EMATECH project data on cost/performance was used to better define test vehicles.
- industry standard practices, or as close to them as possible, needed to be used for the test vehicle design and the manufacturing variables.
- Use of the JEDEC standard for pitch size. "1'here were no standards for many component types. IBM and Motorola had their own standards.
- FR-4 was ranked high and then polyimide. FR-4 is widely used and also has larger differences in Coefficient of Thermal Expansion (CTE) with BGAs, compare to polyimide. FR-4 would provide the most conservatively reliability test results.
- The 300 1/() BGAs were considered to be norm where BGAs compete with leaded packages. The 600" 1/() would be expected in the near future in BGA packages. Both plastic BGA and ceramic BGA packages needed to be evaluated.
- No interest at this time in evaluation of ceramic column grid array because it was not expected to be commonly used and there was no plastic column grid away for reliability comparison.
- Evaluate both full array and peripheral array because of concerns about the reliability of solder joints under the die.
- Characterization of solder paste is important.
- Solderability is important and must be evaluated. At the package level solderability is OK, but at the assembly level solderability needed to be tested.
- It was very important to use dies even though costly. Regarding power cycling, resistive die were used.

- Underfilling was generall y done to promote thermal enhancement and vibration tolerance, but did not contribute to reliability.
- The J]]], study indicated the importance of vibration and mechanical shock. The effect of vibration needed to be investigated further.
- Only edge balls could be detected visually and by SEM. The best way to monitor crack i ni tiation and propagation needed to be defi ned.
- J1'1. previousl y used Anatech® to continuous] y monitor for electrical opens. New monitoring systems with less noise were needed. Cross-sectioning could also be done.
- It was the ball height after reflow, rather than the ball size that was thought to affect solder joint reliability.
- Solder volume was said to be more critical for some types of package than others. It was important to include solder volume as a variable in the 1)esign of Experiment (DOE) test program,
- Surface finish plating, i.e., hot air leveling (1 IASI .), or use of organic solder preservative (OSP) are important and should be considered.
- Solder mask was shown to be a factor affecting reliability.
- Need to look into underfilling and conformal coating as affecting reliability.

Subsequent to the Workshop and after extensive (discussion and further ranking of the variables discussed, the following most critical issues were identified:

- Determine a suitable inspection technique for BGA packages, particularly after they have been attached to the substrate, Evaluate:
  - V X-ray systems: Nicolet, Fein 1 'ocus, and Four Pi
  - O Acoustic imaging systems; Sonoscan
  - O Visual inspection for peripheral solder joints
- . Decide the optima] package type array configuration.
  - O Peripheral array versus full area array and depopulated packages
  - ◊ Overmolded plastic vs. metallic version (Super BGA)
- Characterize the reliability differences between ceramic and plastic BGAs.
  - O Thermal cycling including a military version and power cycling
  - O Vibration behavior
  - O Robustness and reliability compared to fine pitch QFP
- Assess the various techniques for reworking AAP/BGA packages.

CERAMIC AND PLASTIC PACKAGE DIMENSIONAL PROPERTIES

PACKAGES

Packages cover the range from OMPAC to SuperBGAs from Amkor/Anam. In SBGA, the IC die is directly attached to an oversize copper plate providing a better heat dissipation efficiency. The copper plate also acts as a stiffener and ground plain for the package. The solder balls for plastic packages are eutectic (63 Sn/37Pb).

Ceramic packages were from IBM. Ceramic solder balls have 0.035 inch diameters and have a high melting temperature (90Pb/10Sn). These balls are attached to the ceramic substrate with eutectic solder (63Sn/37 Pb) material. At reflow, substrate eutectic material and the PWB eutectic paste reflow to provide the electro-mechanical interconnects.

Figures 3 shows Scanning Electron Micrograph (SEM) photos of ceramic packages with 625 I/Os with straight and tilted solder balls.

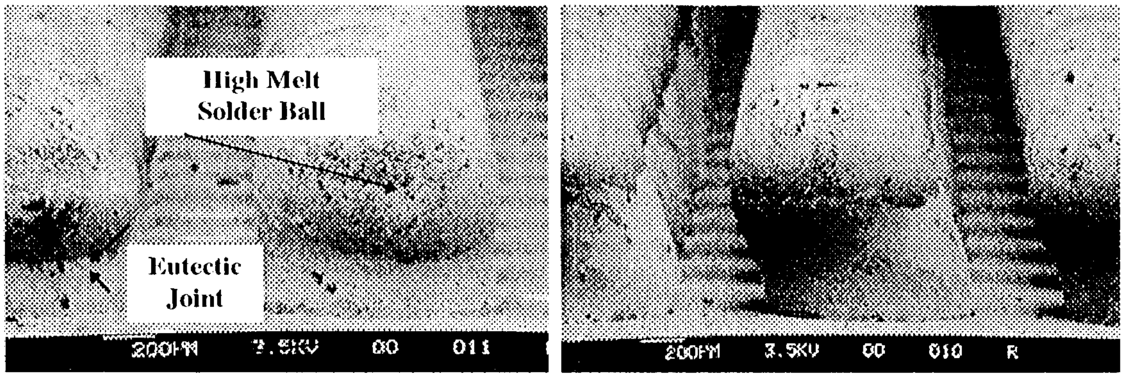


Figure 3 Solder Balls With no Tilting (left) and with tilting in 625 CBGA

PACKAGE DIMENSIONAL CHARACTERISTICS

Package dimensional characteristics are among the key variables that affect solder joint reliability. Dimensional characteristics of all packages were measured using View Engineering 3-D laser scanning system. Output of measurements included solder ball diameter, package warpage, and coplanarity,

Package coplanarity is defined as the distance between the highest solder ball (lead for QFP) and the lowest solder ball. Coplanarity can contribute to the yield of surface mount manufacturing as well as long-term solder joint integrity. For leaded parts such as QFP, nonplanarity in excess of 0.003 inches is not acceptable. JEDEC specification for coplanarity requirement was 0.006 inch which increased to .008 inch.

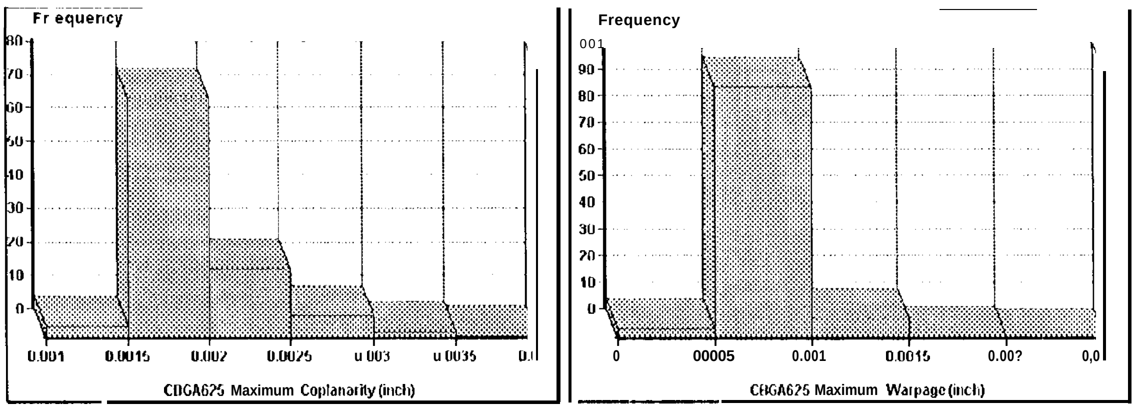
in this paper, the results of package properties for 625 CBGA and 560 Super BGA will be given only. These data are being used to determine the influence of these parameters on the solder joint number of cycles to failure.

DIMENSIONAL CHARACTERISTICS FOR CBGA 625

Figure 4 shows histogram plots of coplanarity and warpage (distributions for 108 ceramics with 625 1/0s and coplanarity distribution for a package with the maximum coplanarity of 0.0042. inch. Results from these and similar plots are:

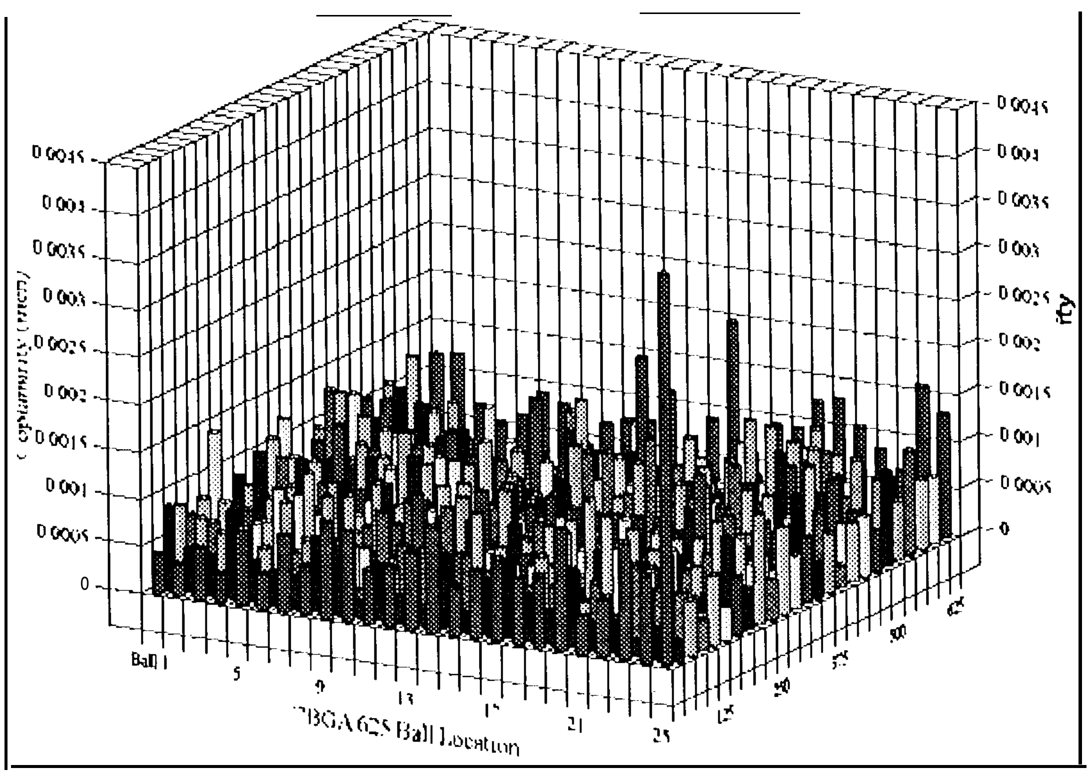
- The balls' coplanarities were 0.0015 to 0.002 inches for 104 parts and 0.003 to 0,0042 inches for 4 parts.
- Maximum solder ball diameters were 0.0315 to 0.0334 inches with minimums 0.028 to 0.029 inches. Diameters were measured only for 36 parts.
- Maximum warpages were 0005 to 0.0029 inches.

The coplanarity (distribution plot for this part reveals that the solder balls were general] y uniform in height with a few at two extreme levels that were randomly distributed.



a) Maximum Coplanarity Distribution

b) Maximum Warpage Distribution



c) (planarity Distribution for a CBGA 625 Package

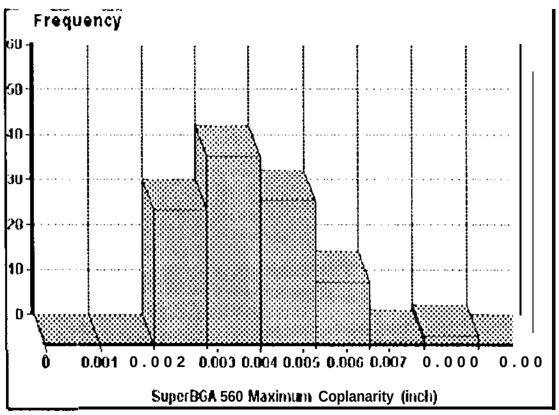
Figure 4. Package Dimensional Characteristics of Ceramic BGA with 625 I/Os

DIMENSIONAL. CHARACTERISTICS OF SUPERBGA 560

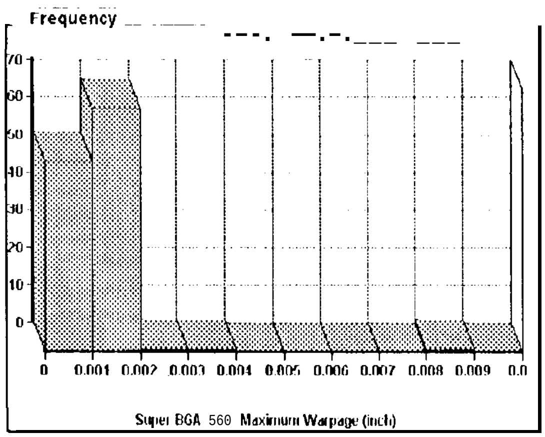
Figure 5 shows histogram plots of coplanarity and warpage for 120 SBGA560 and the coplanarity (distribution for a package with the maximum coplanarity of 0.0054 inch. Results of these and similar plots are as follows:

- Ball coplanarities were 0.002 to 0.004 inches for 72 parts, 0.004 to .006 for 45 parts, and 0.006 to ().()()766 for 4 parts.
- Maximum solder ball diameters were 0.0275 to 0.0290 inches, minimums were 0.0213 to 0.0263 inches.
- . Maximum warpages were 0.001 65-().()096 for 110 packages, 0,01012-0.021 inches for 8 packages, and 0.034 inches for one package.

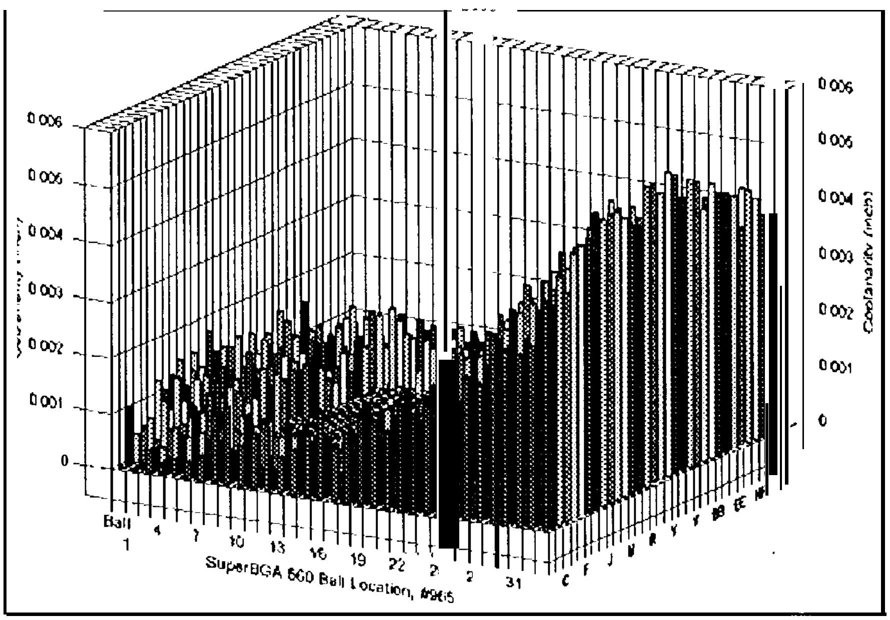
The coplanarity (distribution plot for this part reveals a nonuniformity where one region shows higher heights than the other. Such nonuniformity could cause package lifting during reflow; thus, increasing the likelihood of manufacturing defect formation.



a) Maximum Coplanarity Distribution



b) Maximum Warpage Distribution



c) Coplanarity Distribution for a SuperBGA 560 Package

Figure 5. Package Dimensional Characteristics of SuperBGA with 560 I/Os

SUMMARY OF BGA PACKAGE DIMENSIONS

Package dimensional characteristics as well as PWB's are among the key variables that affect solder joint reliability. Dimensional characteristics of seven package types packages were measured using View Engineering 3-D laser scanning system. Output of measurements included solder ball diameter, package warpage, and coplanarity. Packages were also inspected visually, by SEM, and the results were documented.

Table 2 summarizes dimensional characteristics of two ceramics and five plastic packages. 1 'ive of package types were from Amkor/Anam, the largest manufacturer of plastic packages, cover the range from OMPAC to Super 13(3As. Ceramic packages were from IBM. It is seen that depending on the type of packages i.e. ceramic or plastic and maturity of the package, the variations arc different,

'1'able 2 Dimensional Characteristics of Ceramic and Plastic Packages Determined by View Engineering 3-D Laser S ystem

Package Type	Coplanarity Range (inch)	Warpage Range (inch)	Max. Diameter Range (inch)*
CBGA 625	**.0015 -.002** for 104 .0030-.004 for 4	**.0005 -.0029**	.0315 -.0334
CBGA 361	.0012-.0022 for 102	.0005-.0018	.0312 -.0335
560 **SuperBGA**	.002 -.004 for 72 .004 -.006 for 45 .006 -.0077 for 4	.0016-.009 for 110 .010 -.0?1 for 8	.0275 -.0?9
352 SuperBGA	**.0014 -.0037** for 145 ,0048,,0058,.0065,.009 1	.0013 -.003	.0278 -.02$7
352 **OMPAC**	.0024- .0057 for 128	.002 -.006 for 111 .006 -.010 for 17	.0275 -.0288
313 OMPAC	.0022- .0052 for 140	.0021-.0045	.0285 -.0296
256 OMPAC	.0021 -.0047 for 140	.00?.59-.0047	.0?70-.02.89

* These values are lower than the solder ball diameter true values.

SOLDER 11A].]. DIAMETERS

Solder ball diameters as measured by View Engineering do not agree with the values reported by IBM. Ceramic packages usc high melting solder balls with ().()35 inch diameter. The values from the 3-D laser images for both 361 and 625 1/os were lower than 0.035 inch. In IBM's recent random measurements of ball diameter measurements of

50 out of **300,000,"** as part of their incoming inspection, the values were within their hall diameter specification.

One possibility is that even though the View Engineering system is accurate for measuring coplanarity and other dimensional parameters, it is not accurate for solder ball diameter measurement. A solder ball diameter is calculated from a mathematical curve which is filled to the laser image of the ball. Therefore, the estimated diameter depends on how well the fitted curve is representative of the actual shape of the ball.

Another possibility could be due to the tilt and skewness of solder balls as shown in Figure 3. The tilt could cause distortion in the image detected by laser scanning, resulting in different values than those reported by **1** BM. Diameter of solder ball were measured using the SEM as shown in Figure 1: it was found to be 0.0355 inch.

CONCLUSIONS ON BGA PACKAGE DIMENSIONS

- Solder ball planarities were significantly higher for plastic than for ceramic packages. PBGAs, however, are more robust and the large planarity values might not be a detriment on the solder joint reliability. Some planarity differences among the balls are accommodated by their collapses during the reflow process. This is not the case for CBGAs where high melt solder balls remain intact during reflow. The solder ball diameter controls the stand-off height which is a key factor to solder joint reliability.

- 3-D laser scanning is excellent for characterization of package dimensions, but possibly not for solder ball measurement. It did read lower values for ceramic solder ball diameter than was actually true. One possible cause could be due to the skewness of the ceramic solder balls observed visually and by SEM.

LESSONS LEARNED ON BGAs

- Parameters toggled in the DoE test matrix were well thought out and discussed in details at JPL's Workshop and weekly telecones.
- Face-to-face meetings were very valuable and demonstrated a concurrent engineering approach. Several follow up face-to-face for more thorough review was necessary, but was limited to telecons. This cause some flaws in the PWB daisy chain design
- A model that can simulate TVs' daisy chains and correct the inconsistancies is highly desirable.

- The test vehicle design had numerous valuable features; one was the ability to remove each individual package as discrete independent. These features should be included in other future test vehicle design.
- The corner balls of CBGA 361 were excluded from the daisy chain pattern by IBM design so that reliability could be increased. We were unable to include these balls in our study even though corner lands on PWBs were daisy chained. 'l'his must be considered when reliability data from this package will be compared to other ceramic packages that include the corner balls daisy chain design.
- Ceramic packages showed lower warpage and were more coplanar than their PBGA counterparts.
- Numerous ceramic packages had tilted solder balls, These packages should be inspected for skewness of ball attachment.
- Planarity and warpages were unexpectedly higher for the few PBGA packages. These packages must be inspected particularl y careful] y to assure conformance to the requirements.
- Being in early production at the time of evaluation, a number Super BGA packages showed missing balls due to handling.
- Many ceramic balls showed signs of skewness when visually were inspected.
- QFPs were extremely susceptible to handling damages, many of them were damaged prior to assembling.
- Polyimide yield was lower than epoxy due to some delamination. Polyimide showed more edge and tooling hole fractures from pinning and handling operations, as reported by Alt ron , Inc.
- In solder mask defined pads, some of the via holes had mask in the hole. Some a s k degradation was observed by Altron due to the Ni/Au process temperature.
- The SMD technique for pad coverage was selected based on Motorola's past experience with 1'11(3A's, Motorola's recent investigation (A. Mawer, Surface Mount Iternational Proceedings, Sept. 1996) indicated a possible three fold increase in reliability when NSMD for both package and PWBs are used.
- Selection of the right amount of solder paste volumes and 50% stencil step down all owed successfull y assembling, of test vehicles with mixed technol og y packages. Ceramic and plastics packages as well as fine pitch QFPs were successfull y assembled in one reflow process step.
- As expected, BGAs were robust in assembling compared to the 256 QFPs. The void levels were the same as those generally observed by Celestica on other assemblies, All of the QFPs, however, showed bridging and had to be reworked.

- Robustness of BGAs was also apparent at RIT. RIT dealing with very limited resources was successful in assembling the majority of BGAs whereas had many problems with QFP placement and were unable to eliminate solder bridging.

. It is very important to understand the reasons for solder proms reflow time and temperature in order to be able to assemble packages with different thermal dissipation properties. This knowledge allowed successful assembling of TVs in an 1 R oven at 1<1'1'.

. RMA and water soluble reflow profiles arc different and are not interchangeable and they should be optimized separately fm the applications. When the water soluble reflow profile was used for an RMA paste, solder joint showed excessive voids. This technique can be used to generate different voids levels when investigating the effects of voids on solder joint reliability.

. PWBs with different surface finishes were successfull y assembled. Thermal performance prior to assembl y was not established.

- Cleaning of BGA for RMA flux should be considered when commercial facilities arc used ,

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ACKNOWLEDGMENTS

The research described in this publication is being carried out by the Jet Propulsion Laboratory, California" Institute of Technology, under a contract with the National Aeronautics and Space Administration.

1 special thanks to lb-s. J. Evans and Greenfied, NASA 1 IQ Code Q, D. Howard, QA Office Manager, and P. Barela, QA Applications 1 Engineering RTOP Program Manger, for their visions, invaluable supports and continuos encouragement.

Author sincerely appreciate cooperative efforts of the SMT RTOP program managers Drs. S. Cornford, R. Ross Jr., A. Wen, and Dr. J.K. Bonner. Thanks to S. Walton and for environmental testing. Acknowledge in-kind contributions and cooperative efforts of BGA consortium team members including: P. Barela, K. Bonner, K. Yee, S. Bolin, C. Bodies, S. Walton, *JPL*; M. Andrews, *ITRI*; S. Lockwood, M. Simeus, 1'. Drake, *HMSC*; I. Sterian, B. Houghton, *Celestica*; M. Ramkumar, *RIT*; *S. 1* mine, R. Lecesse, *Altron*; P. Mescher, *AMKOR*; Dr. N. Kim, *Boeing*; W. Goers and J. Mearig, *EMPF*; M. Cole, A. Trivedi, *IBM*, and 'I'. Tarter, *AMD*; F. Schlieper, C. Walquist, *Nicolet*; *R.* Dudley, R. Balduf *View Engineering*, W. Szkolnicki, *Loral (lockheed-Martin)*. My deepest appreciation to others who had or are being ~~contributing~~ to the progress of both programs. been

Contributors

BIOGRAPHY

Dr. Reza Ghaffarian has more than fifteen years of industrial and academic experience in mechanical, materials, and manufacturing processes engineering. At JPL, he supports research and development activities in SMT for infusion into NASA's missions including projects in advanced electronics packaging, interconnection, and assembly. His responsibilities include technical coordination, Design of Experiment (DOE) statistical test vehicle implementation, manufacturing process, inspection methodology development, failure analysis, and environmental test data collection and analysis. Dr. Ghaffarian has authored or co-authored over 25 technical papers and numerous patentable innovations. He has also organized and chaired many technical sessions. He received his M.S. in 1979, Engineering Degree in 1980, and Ph.D. in 1982 all in engineering from University of California at LOS Angeles (UCLA).